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ABSTRACT

Designed to examine the structural differences in the representation of medical problems in subjects with varying degrees of medical expertise, this study uses an online, thinking-aloud technique to investigate the validity of Feltovich and Barrows' model of expert medical knowledge and illness scripts. Study methodology involved asking one medical expert, two intermediates, and a novice to think aloud while being presented with 48 cards arranged in sequential order that characterized the patient or presented history and physical or lab findings for a clinical case of alcohol-induced pancreatitis. The subjects were also asked to provide a differential diagnosis after viewing all 48 cards. Study results indicate that the model is congruent with the elaborate, interrelated structure of the expert subject's case representation, which contained no basic science propositions, but not with the novice and intermediate protocols, which did utilize basic scientific knowledge. It is concluded that these findings affirm the proposition of a direct relationship between characteristics of the knowledge structure and the accuracy of the outcome of the problem-solving process, and it is suggested that an addition to the model is needed to describe how knowledge is activated and applied at different levels of medical expertise. The text is supplemented with 2 figures, and 15 references are provided. (KM)

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ON-LINE REPRESENTATION OF A CLINICAL CASE AND THE DEVELOPMENT OF EXPERTISE

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ABSTRACT

An on-line, thinking aloud methodology was utilized in order to investigate the clinical case representation of subjects who differed in terms of their levels of medical expertise. The analysis technique was derived from an existing model of expert medical knowledge. The results revealed that the model was congruent with elaborate, inter-related structure of the expert subject's case representation. However, large deviations from the model were found in the think-aloud protocols of the non-expert subjects. It is suggested that an addition to the model is required in order to describe how knowledge is activated and applied at different levels of medical expertise.

INTRODUCTION

Semantic structure models of human learning emphasize qualitative, structural rather than incremental, quantitative changes in knowledge (Glaser, 1980). That is to say, developing expertise is characterized by the development of elaborated inter-relationships between aspects of a factual knowledge base already possessed, rather than by the simple accumulation of new factual knowledge.

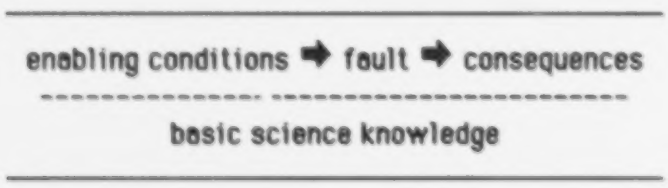
As has been shown by many investigators (e.g. Chi & Glaser, 1980, De Groot, 1946, 1965; Larkin, McDermott, Simon & Simon, 1980) experts and novices differ in terms of their knowledge structures. These effects are reflected in of their representation of a problem (Glaser, 1980). In addition, problem representation and the outcome of the problem-solving process are closely related. In medicine this relation shows itself in the close correspondence between the initial problem representation that a physician or student generates and the final diagnosis (Elstein, Shulman & Sprafka, 1978: Barrows, Feightner, Neufeld & Norman, 1978). Further evidence for this relation is provided by Lesgold and his collegues (Lesgold, Feltovich, Glaser & Wang, 1981; Lesgold, 1984) who studied the diagnostic skill of expert radiologists, intermediates and novices. These investigators were able to relate diagnostic errors to characteristics of the knowledge structure that was applied in the problem. For instance, failure in the intermediate group could be due to imprecision in their knowledge of anatomical structures, to limitations in the knowledge about how these structures vary normally and under perturbation, or, to deficiency in mapping this anatomy onto the markings of an X-ray (Lesgold, 1984). Recently, Patel & Groen (1986) investigated the knowledge structures of seven cardiologists who were presented with a case of acute bacterial endocarditis. The subjects' case recall protocols and their description of the underlying pathophysiological process were analyzed with respect to the knowledge (production rules) that was applied in diagnosing this case. It turned out that the unsuccessful subjects used a different set of rules than the successful subjects did. In addition, the successful subjects utilized forward chaining rules, whereas at least some of the rules the unsuccessful subjects applied were backward chaining rules. So, the analyses showed a direct link between the characteristics of the knowledge structure that was applied and the accuracy of the outcome of the diagnosis.

According to Feltovich & Barrows (1984), whose ideas are based on Clancey's work in Artificial Intelligence in medicine (Clancey, 1983), expert medical knowledge about any specific disease can be characterized by an integrated model of the disease or "illness script". Such a script contains three types of knowledge:

1) Knowledge about the conditions that may lead to a disease, which are termed the enabling conditions. These are the predisposing factors, boundary conditions and hereditary factors which can make an individual of a certain sex and age, with his or her social and hereditary background in this specific situation more or less susceptible to illness in general or to an illness of a specific kind.

2) Knowledge about the disease process itself: the faults (e.g. infection, metabolic disorder, invasive growth into tissue, trauma and degeneration).

3) Knowledge about the signs and symptoms which characterize the disease: the consequences.



In the Feltovich and Barrows model these illness scripts are at the core of medical knowledge and clinical reasoning. In their view, a clinician attempts to represent and understand a patient problem by constructing an integrated script or scenario for how this patient's condition came to be, its major points of malfunction and its subsequent associated consequences. In the construction of these scripts basic science knowledge (e.g. anatomy or pathophysiology) plays an integrating role by constraining and guiding the manner in which script components can be structured together. A diagnosis is made when the script is instantiated.

The aim of the present study is to investigate structural differences in the representation of medical problems in subjects with varying degrees of medical expertise, using an on-line technique (Ericsson & Simon, 1984). Therefore, think-aloud protocols of one expert, two

intermediates and a novice were analyzed in order to investigate whether differences could be observed in the way these subjects represented a clinical case and how these structures may be reflected in their final diagnosis. In doing this the Feltovich and Barrows (1984) model of expert medical knowledge was taken as a working hypothesis.

EXPERIMENTAL METHOD

Subjects

Four subjects at different levels of medical expertise participated in this study. One was a true NOVICE (in the following indicated with N) who was a second year medical student. The two INTERMEDIATEs were a fourth year student (I-1) who nearly finished his pre-clinical training and a fifth year student (I-2) who finished both an internal medicine and a primary care clerkship. The EXPERT subject (E) was a family physician with about four years of experience after registration.

Procedure

The subjects were presented with a case of chronic relapsing alcohol induced pancreatitis with minor pancreatic insufficiency. The patient in the case description, a 38 year old, unemployed male, has a long history of depressions and mental problems which enabled alcoholism. His alcohol consumption which increased over six years, enabled an attack of pancreatitis one year earlier. With the aid of medicines (Refusal) he refrained from drinking for half a year, but then there was a new outburst. After this, he developed poor feeding habits and lost weight. Now he has no appetite and eats irregularly. And aside from the alcohol, a substantial part of his calory intake comes from fatty foods: meat balls, sausages, french fries, oily salads, etc. One year after his attack of pancreatitis and the abstinence cure, he develops a new attack induced by the consumption of a large amount of booze and some sleeping pills two days earlier, when he attempted suicide. Now he calls the family physician with a complaint of severe, boring pain in the upper part of the abdomen.

The case was presented on 48 cards. Each card contained one or more items which characterized the patient or presented history, physical or lab findings. Part of this

information, the history of mental problems, depressions, increasing alcohol consumption, the previous attack of pancreatitis and the (subsequent) abstinence cure, was provided to the subject before the actual complaint was presented; further information was given 'in the course of the doctor-patient contact'.

The subjects were asked to think aloud while being presented with the cards in a sequential fashion and to provide a differential diagnosis at the end. These sessions were recorded on tape. Verbatim transcripts were produced from these tapes.

Analysis

The original case was analyzed[1] using the Feltovich and Barrows model and was found to contain two major, inter-related scripts, an alcoholism script and a pancreatitis script (see figure 1). The inter-relation is reflected in the case diagnosis, which is chronic relapsing alcohol induced pancreatitis with minor pancreatic insufficiency.

-insert figure 1 about here-

RESULTS

In order to investigate the subjects' problem representation, the links they made between the individual case findings and with the hypothesis that were generated, were traced. As Feltovich and Barrows distinguish enabling conditions to and consequences of a fault, findings belonging to these two different classes were treated separately. Basic science underpinning of these links and the relation between problem representation and final diagnosis were investigated as well.

Enabling conditions

In order to gain some insight into the role of enabling conditions in the subjects' problem representation, the responses to the first 8 items of the case description were analysed. These

[1] With the invaluable assistance of Pie Hobus.

items are on the patient's personalia (1), his history of mental problems (2) and neurotic depressions (3), his alcohol abuse (4), the attack of pancreatitis (5) and the abstinence cure (6), the time and location of the consult (7) and the patient's presenting complaint (8). (item numbers are between parentheses (*))

- insert figure 2 about here -

As can be seen in figure 2, there are marked differences between the NOVICE, the INTERMEDIATEs and the EXPERT.

E begins to combine enabling conditions when he learns about the patient's neurotic depressions and an admission to mental hospital of a three months' duration (3). He relates it to the patient's age (1) [pl 8] (protocol line numbers are between brackets [pl *]). The next item (4) is about the patient's increasing alcohol consumption and E concludes that it is a very bad omen when a person of this age in these circumstances starts drinking alcohol in increasing quantities [pl 20 - 24]. The attack of pancreatitis (5) is immediately linked to the drinking habits (4) [pl 25], and after hearing the presenting complaint (8), he combines enabling conditions to generate some hypotheses about the fault that causes the patient's complaint. Another fault that may result from a high alcohol consumption (cardiomyopathy) is hypothesized as well. He says:

> E [pl 33 - 44]: "Well, when I visit a person with an acute, continuous (for how long?) pain in his abdomen, radiating to the back, who suffered from pancreatitis a year before, where I don't know for sure whether or not he is still drinking after the Refusal cure, but I do know that his mental problems still exist, well the first thing I think is: in what condition is his pancreas, in what condition is his liver? and that - because of his age - other, malign processes in his abdomen are less probable. Of course, when he drinks a lot, he may have a gastric problem as well, a perforation of the stomach. And a high alcohol consumption can cause a severe cardiomyopathy, which can give heart problems."

In response to the same items, I-2 says three remarkable things.

About the alcohol consumption (4), he says that he must reckon with the liver [pl 16]. He attributes the attack of pancreatitis one year earlier (5) to alcohol abuse (4) [pl 18]. And in the think-aloud protocol, he implicitly links the complaint (8) to the patient's age (1):

> I-2 [pl 24]: "He was 38 years old, I think (....)",

suggesting that it is important to consider the patient's age at this moment, but without an indication of the reason for that.

I-1 doesn't link the presenting complaint (8) to any of the enabling conditions. He comes up with hypotheses about pancreas and gall but doesn't indicate why he comes to think of these [pl 12 - 13]. He does relate the earlier attack of pancreatitis (5) to alcohol consumption (4) [pl 7], as did I2 and E.

N relates alcohol consumption (4) to the patient's history of neurotic depressions (3), and pancreatitis (5) to alcohol consumption (4). About this last relation he says:

> N [pl 22 - 25]: "I wonder whether this can be related to alcohol consumption, but I don't know by now how that could be. I don't know anything about it."

In the next item (6) he seeks confirmation for this hypothesis, but cannot come to a conclusion [pl 27 - 31]. However, this absence of knowledge doesn't keep him from furthering the hypothesis that it's again the pancreas causing the patient's complaint (8):

> N [pl 36 - 39]: "The upper part of his abdomen, there we are again at his pancreas. Radiating to the back, tells me very little at the moment".

This link seems to be based primarily on the location of the pain.

Although each subject linked alcohol consumption to pancreatitis, only the expert used this relation in favor of his hypothesis of pancreatitis when learning that the patient resumed drinking after a half year's period of abstinence (19) [pl 92 - 94].

These fragments clearly suggest that the expert uses his knowledge about enabling conditions to create a rich network of hypotheses which are activated for further consideration when new information comes in, whereas the novice and the intermediates although being able to inter-relate some of the material, suggests that they are not really able to use the initial information provided in constructing a multifaceted representation of the conditions of the patient.

The consequences of the fault

In the process following this initial phase, EXPERT E actively rules out several hypotheses stated initially. In the course of this process he effectively utilizes his knowledge about signs

and symptoms of the hypothesized faults. The same is done by INTERMEDIATE I-2. However, there is one important difference. The criteria I-2 applies in the course of this process are not always very realistic. For instance, after learning the patient doesn't look sick (21), he says:

I-2 [pl 74 - 75]: "Well, pancreatitis, those patients must look sick (.....)".

In other words, he does not take into account the variability in acuteness and seriousness of the disorder. And concerning the patient's temperature, which is normal (33):

I-2 says [pl 113]: "In an acute pancreatitis it must be higher".

I-2 appears to maintain a rather typical and inflexible representation of pancreatitis, lacking with respect to the various ways in which pancreatitis may manifest itself and the different courses it may take.

INTERMEDIATE I-1's reasoning process has a different outlook. He is primarily concerned with the exact location of the fault in the body and reasons about that first. He concluded that it must either be the patient's pancreas or his gallbladder that is causing his trouble. Later on in the protocol the pathophysiological process is taken into account. For instance from the normal temperature and heart rate (33 and 34) he concludes:

I-1 [pl 73 - 80]: "So no fever. That last two items indicate that there is no infection, actually .. and that would rule out eh .. eh .. cholecystitis and so .. eh .. rather it be a biliary obstruction .. by a stone for instance .. or, that could be possible too, by a carcinoma .. but then, oh yes, it could be .. lost 5 kilos".

This subject's knowledge about pancreatitis, the pancreas and the pathophysiological processes that take place appears to be not yet very well integrated.

These results suggest that EXPERT E's use of enabling conditions give him a headstart to NOVICE N and INTERMEDIATEs I-1 and I-2 who must compensate for this by matching findings to faults, but in doing so, are handicapped by defective or badly integrated knowledge.

Basic science knowledge

Only in NOVICE N's protocol, basic science knowledge plays an eye-catching role in his efforts to relate diagnostic findings. However, because of this absence of relevant knowledge, he

constructs ad-hoc theories which cannot be confirmed by other findings. These naive theories all end up in a deadlock.

Here are two examples:

Responding to item (48a) about increased serum amylase

> N states [pl 192 - 197]: "So that is markedly increased. Amylase, that is starch[2] I think. So eh he will have pancreatic dysfunction and that's why less starch is transformed into glucose, resulting in a raised starch level. Well, then you think of beta-cells producing insuline."

And next, after a new lab finding on increased glucose (48b) he states

> N [pl 198 - 200]: "That is slightly increased, but how that can be related to a starch level that is increased as well, I really don't know".

Trying to account for the patient's poor eating habits, N remarks on the loss of appetite (24)

> N [pl 113]: "That will mean that he gets more complaints when he is eating certain food-stuff or by eating in general".

Then he reads that the patient eats irregularly (25) and he states

> N [pl 114 - 116]: "That means the same. Perhaps he only eats when it is really necessary and further actually avoids eating as much as possible."

Two items later, he learns that the pain has no relation to meals (28), and then he says

> N [pl 125 - 126]: "Now I wonder why he eats so infrequently and so irregularly".

Neither in the INTERMEDIATEs' nor in the EXPERT's protocol such explanations are found. In their protocols no explanations of underlying pathophysiology are found, that are based on basic science knowledge, semi-knowledge or non-knowledge.

As has been shown, in INTERMEDIATE I-1's protocol basic science knowledge is used in a different way. First he applies knowledge about anatomy and pathophysioplogy, attempting to identify the location and nature of the fault before proceeding to the next step in which the final diagnosis has to be found. In the first part of the process he decided that the cause of the symptoms would either be located in the patient's pancreas or in the gallbladder, and after learning the patient resumed drinking (19), the liver plays an important role in his thinking. He decided on biliary obstruction because the patient has intermittent icterus (23), but after the

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[2]Amylase is a pancreatic enzym, which plays a major role in the fermentation of starches. In pancreatitis it is released in high quantities into the blood stream.

finding of a normal temperature and heart rate (33 and 34), he concludes that an infection has been excluded.

In the other subjects' protocols no traces of basic science knowledge application have been found.

Further exploration into problem representation

Some other striking phenomena in problem representation are to be mentioned.

Lack of knowledge.

The NOVICE subject lacks knowledge of the meaning of concepts or entertains a wrong interpretation. For instance in response to the abstinence cure (6) he states:

N [pl 26]: "I don't know what that is, Refusal"

And about the lab finding of an increased serum amylase (48a)

N [pl 193]: "Amylase, that is I think starch"

Similar phenomena do not occur in the INTERMEDIATEs' and EXPERT's protocols. These subjects seem to have aquired knowledge that enabled them to at least understand the information provided.

Inability to understand the implications of findings.

The NOVICE and INTERMEDIATE I-1 are not able to interpret information which is in itself understandable.

Responding to the patient's remark that he tried Aspirins which did not influence the pain (18), both N and I-1 indicate their inability to do anything with this finding.

N [pl 88 - 90]: "Well, Aspirins are used against the pain most of the time. Why they didn't have effect, don't ask me, because I don't know".
I-1 [pl 37]: "That doesn't tell me anything"

This is in sharp contrast with INTERMEDIATE I-2's and the EXPERT's response.

I-2 [pl 58]: "Yes , Aspirins, they are bad for the stomach"
E [pl 85 - 90]: "Aspirins, that is always nice with people with gastric problems and alcohol consumption. Raises the chance of an ulcus, raises the chance of a perforation. They had no effects. That could mean that he took a large dose to relieve the pain, and because of that, extra raised the chance of a perforation of the stomach, of a gastric ulcer or a bleeding ulcer."

This phenomenon of not being able to see the implications of information is also apparent in the NOVICE's repeatedly expressed need for further information. Responding to the information that the pain increased since that morning, but is now at a constant level (10), N needs more information.

> N [pl 55 - 57]: "That indicates that it was not at a constant level before. Under what circumstances was it and under what circumstances was it not constant?".

This asking for more information appears to happen in a haphazard fashion and is data-driven to a large extent, whereas the expert's need for information is part of a systematic planning of the problem solving process. For instance, in response to the attempted suicide (20), the physician asks:

> E [pl 98 - 110]: "What did actually happen? Very little apparently. Why 6 pills only? Someone who wants to do it well, takes more that 6 Mogadon. Who gave him that Mogadon? (... [pl 103] ...). You cannot neglect this information, but before pursuing this, (... [pl 105 - 109] ... summarizes important findings) I would make sure whether something is really wrong with him"

To conclude, three phenomena are found: a) clearcut lack of knowledge in the NOVICE subject, b) his efforts at constructing meaning by idiosyncratic theorizing, and c) the NOVICE 's and INTERMEDIATE I-1's inability to see the implications of at least some of the findings and associated with that N's lack of a systematic planning of the problem solving process.
These results suggest that NOVICE N's knowledge is not sufficient with respect to the present problem, whereas INTERMEDIATE I-1's knowledge is in itself sufficient to interpret all the findings but does not enable him to see the implication of the findings. Their knowledge about pancreatitis and the conditions enabling it, seems to be scattered.
Apparently it cannot be utilized as a schema for constructing a mental representation of the problem or as a frame of reference for information search.

problem representation and diagnosis

In the differential diagnosis that the subjects provided, the effects of some phenomena described in the two earlier paragraphs can be traced. Most clearly these effects come forward in the INTERMEDIATES' protocols. In this section focus will be primarily on these subjects' performance.

INTERMEDIATE I-1's differential diagnosis shows the traces of his misconception about infection and fever. His DD contains two elements: carcinoma of the head of the pancreas and intermittent obstruction by bile stones in the major duodenal papilla. In the first part of the process he decided that the cause of the symptoms would either be located in the patient's pancreas or in the gallbladder, and after learning the patient resumed drinking (19), the liver plays an important role in his thinking. He decided on biliary obstruction, because the patient has intermittent icterus (item 23), but after the finding of a normal temperature and heart rate (33 and 34), he concludes that an infection has been excluded, so cholecystitis is highly improbable. In his view, something else obstructs the bile flow, a stone, or a carcinoma. At the end of the process, he applies his conclusion that there cannot be an infection to the presumed location of the process at hand: the pancreas (suggested by the finding of an increased serum amylase (46a))

> I-1 concludes [pl 129 - 134]: "Probably a biliary obstruction .. without a real infection .. causing a minor liver (...) dysfunction and lab findings indicating .. eh .. a pancreatic dysfunction (.... and indications of) a carcinoma .. weight loss of 5 kg in half a year time

and then he provides the differential diagnosis.

The oddities that were observed in INTERMEDIATE I-2's protocol where he commented on the patient's appearance (21) and temperature (33), are reflected in his differential diagnosis as well. First in his DD is: chronic pancreatitis, followed by gastritis, liver cirrhosis, carcinoma of the pancreas and malignancy in the pancreas area.

Compared with INTERMEDIATE I-1, I-2's conclusions on the process at hand are not so articulate. Given the patient's appearance, he hesitates about pancreatitis; given a normal temperature, he concludes there cannot be an acute pancreatitis. This conclusion is overturned by a lab finding of increased serum amylase. Hence, the escape of a chronic pancreatitis as a first solution has been taken.

These findings are in line with Patel's and Groen's (1986) conclusions about a close relation between the knowledge that a subject applies in the problem solving process and diagnostic accuracy.

DISCUSSION

The aim of this research was to investigate the validity of Feltovich's and Barrows' model of medical expert knowledge, to investigate the differences in problem representation between a NOVICE, INTERMEDIATEs I-1 and I-2 and an EXPERT and to determine whether these differences have significant effects on the outcome of the problem-solving process. In the previous section the differences between N, I-1, I-2 and E were highlighted, and it was concluded that the observed differences had significant effects on the problem representation and on the final outcome, i.e. defective knowledge resulted in an imprecize or even wrong diagnosis.
The results show some eye-catching differences between the subjects. However, due to the methodology utilized this study has its limitations. In this section we will ponder on these constraints and on the influence they exert on the tenability and generalizibility of the conclusions. First the results will be summarized and some preliminary conclusions will be formulated. Then, we will go into more detail with respect to the tenability and generalizibility of these conclusions and some extra evidence will be presented. Finally, the validity of Feltovich's and Barrows' model of medical expert knowledge will be submitted to a closer examination.

Problem representation, knowledge structure and final outcome.
The results of the present study may be summarized as follows:
a) The EXPERT extensively utilizes enabling conditions to create a rich network of hypotheses, whereas the non-expert subjects N, I1 and I2 are unable to take full advantage of them.
b) INTERMEDIATE I-2's hypothesis testing seems to be hampered by a rigid and typical representation of pancreatitis. Various ways pancreatitis may manifest itself and the different courses it may take are not taken into account.
c) INTERMEDIATE I-1's knowledge is sufficient to interpret many of the findings in isolation, but does not enable him to go far beyond the information given. He does not see the implications of several findings.

d) In addition, INTERMEDIATE I-1 does not apply knowledge about pancreatitis in hypothesis generation, suggesting that at least it does not play a dominant role in his knowledge base. Instead, his primary approach is to try to decide on the exact location of the fault and then to define the process that is taking place in general pathophysiological terms.
e) INTERMEDIATE I-1's and the NOVICE's knowledge about pancreatitis and the conditions that may enable it, appears to be scattered and has not yet been structured into a script. Therefore, it cannot be utilized as a schema for constructing a mental representation of the problem or as a frame of reference guiding information search.
f) The NOVICE's knowledge of pancreatitis is simply not sufficient to handle the problem.
g) The poorly developed and rigidly inflexible knowledge base of the non-expert subjects is clearly reflected in their imprecise or even wrong diagnoses.

These results suggest that knowledge about the topic 'alcohol induced pancreatitis' develops through distinguished stages:
Stage 1 - total lack of knowledge, any knowledge which is exhibited consists of general world knowledge in the form of naive notions or misconceptions
Stage 2 - use of general knowledge of anatomy and disease processes compensating for lack of specific knowledge. Knowledge consists of individual items which have not yet been integrated into scripts
Stage 3 - knowledge characterized by prototypicality and rigidity. What scripts do exist are prototypical in form and are not flexible enough to incorporate multiple forms of the same disease scripts.
Stage 4 - knowledge organized into adaptive scripts containing the different causes that pancreatitis may have, the different courses it may take and the ways it may manifest itself. In addition, the EXPERT can rely on a large amount of knowledge about the conditions that may enable diseases. Defective and imprecize knowledge is reflected in the problem-solving process (information need and information search) and in the accuracy of the outcome.

How strong is the evidence for these conclusions? The NOVICE's lack of knowledge is clear-cut, and is stated by him in several protocol lines. However, the conclusions about prototypicality

and rigidity of INTERMEDIATE I-2's knowledge structure, and about the place pancreatitis takes in INTERMEDIATE I-1's knowledge base, have been derived indirectly. To decide on these conclusions, more confirming information is needed. Some confirming information can be found in the content of the core curriculum of the University of Limburg Medical School. Since pancreatitis is a rather rare disease, it is not part of the core curriculum, although most students will study this subject superficially, to differentiate it from cholelithiasis. Consequences of alcohol abuse are in the core curriculum. However, its impact on the liver and on the nervous system are dominant: pancreatitis is only "in the small print". Alcohol abuse is scheduled in the third year, diseases of the abdomen are in year four. Probably, INTERMEDIATE I-1 does not know very much about pancreatitis. In contrast to that, he studied anatomy and pathophysiology thoroughly in the first and second year, and he is accustomed after 3 1/2 years of experience in a problem-based curriculum, to apply all relevant knowledge when he is confronted with a new problem, even when specific knowledge is absent. Apparently, he handles this case in the same manner.

Differences in knowledge structure seem to pertain to differences in information need and information search. This information need is extreme in the NOVICE subject, whereas to the EXPERT half a word seems to suffice. The NOVICE wants to know more from the patient about nearly every bit of information that he encounters. Primarily, N's search is driven by the data he received. This observation is consistent with earlier, unpublished findings[3] of the present project where subjects were confronted with a part of a doctor-patient encounter. Subjects were asked to indicate what they wanted to do next. Most of the time, the novices (again second year medical students) wanted to know 'more about the same' whereas the intermediates tended to focus on something new that they wanted to explore. This result is in close agreement with the finding in the EXPERT's protocol whose information search seems to be primarily driven by a hierarchy of goals he wants to reach.

Together with the observation of INTERMEDIATE I-1's approach to the problem - location first, then process - the finding of a different information search strategy led to the conclusion that the NOVICE's and INTERMEDIATE I-1's knowledge of pancreatitis is not structured into a script

[3]HFA Claessen and J Verschuuren did these analyses

that can be used as a frame of reference guiding information search or as a scheme for constructing a mental representation of the problem.

Tenability and generalizibility of the conclusions

The conclusions formulated above are restricted to the domain of alcohol induced pancreatitis. Generalizations to other domains of knowledge are not attempted because of the minor role this topic has in the core curriculum of the Maastricht medical school. It remains to be seen whether the same phenomena occur when these subjects are confronted with a case of influenza or a heart attack which are a explicit part of the first year curriculum.
Since the present study utilizes a cross-sectional methodology the subjects' individual developmental course will not necessarily pass through all the stages that are outlined above. Each individual may take a different route, although starting and end points shall be alike.

The validity of Feltovich's and Barrows' model of medical expert knowledge.

It was concluded that the EXPERT relies on a large amount of knowledge about the conditions that may make a person susceptible to a specific disease or to disease in general. Only in the EXPERT's protocol, enabling conditions played a substantial role. The NOVICE, INTERMEDIATE I-1 and INTERMEDIATE I-2 made use of them to generate one or two hypotheses, but they seemed not to be aware of the broad variety of diseases and malfunctions that may result from alcohol abuse. Differences between the EXPERT and the less experienced subjects with respect to the consequences of the fault pancreatitis were found as well. The protocols of INTERMEDIATEs I-1 and I-2 showed some indications of incomplete knowledge about the consequences of pancreatitis. And I-1 actually did not utilize knowledge about pancreatitis, but reasoned in terms of location and nature of the disease process, suggesting that he possesses only minor knowledge of this topic.
With respect to Feltovich's and Barrows' model, these findings suggest that it is a valid model of medical expert knowledge. Their notion of clinical thinking as script instantiation is supported by the data. This process can be recognized in the EXPERT's and in INTERMEDIATE I-2's protocols. Yet, with respect to novice knowledge and problem-solving, this model leaves us empty-handed.

However, to conclude on the model's validity yet another element must be examined. In Feltovich's and Barrows' conception the basic sciences play an integral role in clinical reasoning by constraining and guiding the manner in which script components can be structured together. If basic sciences play such a role, traces or their application should be found in the think-aloud protocols of all the subjects.
The EXPERT's protocol contains no such basic science propositions. On the contrary, only the NOVICE and INTERMEDIATE I-1 utilized such knowledge to interpret and integrate findings. Apparently, the more experienced the subject, the less he relies on basic science knowledge in diagnosing a case of alcohol induced pancreatitis.

Does this absence of references to basic science knowledge indicate that it does not play a role in expert diagnostic problem solving? Does it perhaps indicate that acquiring this knowledge was only a necessary step in the learning process, useful in understanding biological functioning, but not utilized in diagnostic problem solving? In the authors' opinion it does not necessarily indicate this.
For an alternative explanation we must spend some attention to activation and application of knowledge. Feltovich's and Barrows' model of medical expert knowledge as outlined in the introduction to this paper, does not account for the question how knowledge is activated. The answer was left implicit: knowledge is activated by the data perceived, but it is activated as well by the goals the problem solver maintains, or by his or her ideas about the characteristics of an acceptable solution. Depending on the context, the same data can "call for" a more detailed solution than will be needed at other occasions. Script or schema theories about knowledge structure only partially account for this proposition. In most theories, activation is all-or-none. Schemata as Schank's (see Schank & Abelson, 1977) or Minsky's (1975) are activated by elements in working memory. If these elements are present, schemata will be activated as a whole, otherwise they will not.

The results of the present study affirm the proposition of a direct relation between characteristics of the knowledge structure and the accuracy of the outcome of the problem-

solving process. These results also provide a description of the stages that the students' knowledge structure will pass through, in order to attain an expert representation of alcohol induced pancreatitis. Further research into the knowledge representation and problem solving abilities of subjects at various levels of medical expertise is of prime importance for the development of a theory what constitutes clinical competence and the development of a medical curriculum capable of instilling these attributes in students.

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-- figure 1 --

Illness scripts playing a major role in the case description

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alcoholism script:

enabling conditions:

predisposing factors: mental problems
neurotic depressions
unemployment

boundary conditions: - age: 38

fault: dependence on alcohol

consequences: - increasing ....ol abuse since 6 years
- attack of pancreatitis one year before
abstinence cure one year before
- new outburst of drinking after half a year of abstinence
- no appetite
- irregular eating habits
- junk food consumption
- weight loss: 5 kg in half a year time
some liver dysfunction:
intermittent icterus
but no physical findings

pancreatitis script:

enabling conditions:

predisposing factors:

- increasing alcohol abuse since 6 years
- attack of panoreatitis one year before
- new outburst of drinking after half a year of abstinence

attempted suicide two days earlier with 6 Mogadon and large amount of alcohol

- no appetite
- irregular eating habits
- junk food consumption

menu this morning: ham and eggs

- weight loss: 3 kg in half a year time

boundary condition:

- age: 38

call for visit 9 pm of family physician

no parotic swelling

fault:

toxic destruction of tissue due to alcohol

consequences:

* continuous pains in the upper part of the abdomen, radiating to the back
started this morning with vague pain in the abdomen
increasing since then, constant now
severe, boring pain, piercing right through
cannot circumscribe the pain
* sits in a chair, bended forward or with knees drawn up
vomiting did not affect the pain
* pain is similar to the pain in the attack of pancreatitis
only then it started suddenly and was worse
this sort of pain more often in the last time, but now it is worse
almost always these attacks vanished in one day time
* doesn't look sick, but his face is distorted with pain.
pain is continuous, not influenced by meals
paler and more stinking stools

physical:

abdomen moderately distended; moderately moving with breathing
bowel sound diminished
liver and spleen not enlarged
minor gastric tenderness; no guarding; no tenderness in other parts of the abdomen
no other physical findings

* lab:

increased serum amylase;
increased glucose (slightly)
increased WBC (slightly);
increased ESR (slightly);
normal Hg

- = items that are part of both scripts
* = very important consequences

-- figure 2 --

The subjects' processing of a subset of case cues

	subjects: Expert	Intermediate$_2$	Intermediate$_1$	Novice
item:				
1 enabling A male, age 38	X00 0	X 0	X	X
2 enabling A mental problems	X 0 0	X	X	X
3 enabling A neurotic depressions	X0	X	X	X0
4 enabling P*; CA increasing alcohol abuse last 6 yrs	X00	X00	X00	X00
5 enabling P*; CA attack of pancreatitis one yr before	X00	X	X	X00
6 CA*; (fault A) abstinence cure	X0	X	X	X
7 enabling P call for visit 9 PM of family physician	X	X	X	X
8. consequence P continuous pains in upper part of abdomen radiating to the back	X	X	X	X

enabling P = enabling condition for pancreatitis
enabling A = enabling condition for alcoholism
CP = consequence of pancreatitis
CA = consequence of alcoholism

* = first mentioning of item
o = referring to an item while commenting another item